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S. Pytko and K. Bednarek

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16. Abstract Guidelines are given for determining pressure gradients in feed nozzles; for selecting oil mist generators in terms of output, oil and air preheating, and oil refill intervals; for selecting the type and viscosity of oils; for determining the dimensions of compressed-air and oil-mist lines; and for laying out systems without pockets that accumulate condensed oil. A sample system design is presented.

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9. Design Guidelines /104*

9.1. Oil Mist Pressure Gradients in Feed Nozzles

The oil mist pressure gradient in feed nozzles refers to the difference between the pressure of the oil mist fed to the nozzles and the pressure prevailing at the lubrication point (e.g. in a ball bearing housing). The magnitude of the oil mist pressure gradient in feed nozzles is determined as a function of the quantity of oil mist which must be fed to the nozzles at the lubrication points. Under normal operating conditions, the oil mist lubricating system must satisfy the following requirements if compressed air is fed to the oil mist generators under stabilized pressure:

a) The compressor gradient generator in the feed nozzles must be equal to or greater than the projected value.

b) The speed at which the oil mist flows through the lines must be equal to or greater than the projected value which has been calculated for the oil mist pressure prevailing in the lines.

Once the oil mist requirement for the lubricated elements has been determined, the pressure gradient is calculated, which then makes it possible to establish the number and size of feed nozzle openings.

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* Numbers in the margin indicate pagination in the foreign text.

Proper operation of the feed nozzles requires that the following minimum pressure gradients for the oil mist be guaranteed:

1. Oil mist feed nozzles: 50 mm H_2O

2. Spray feed nozzles: 200 mm H_2O

3. Dripping feed nozzles: 300 mm H_2O

4. Spray feed nozzles for direct spraying on the elements with a velocity above 10 m/sec, operating at temperatures equal to or higher than those projected: 1000 mm H_2O

The performance of feed nozzles as a function of pressure gradient can be seen from Table 1.

9.2. Selection of Oil Mist Generators /105

9.2.1. Generator Performance

The quantity of compressed air required by the oil mist generator is equal to the quantity of oil mist which is to be fed to the lubricating points through the feed nozzles. The generator must be selected such that the necessary quantity of oil mist is supplied to the feed nozzles at the given compressed air pressure and the oil mist pressure gradient selected. Generator performance is defined by the technical characteristics specified by the manufacturer. The performance of several standardized generators is shown in Fig. 23 as a function of pressure and of compressed air temperature.

A generator must be selected which also possesses a certain reserve capacity with regard to the quantity of oil mist needed for the lubricating points.

TABLE 1. PERFORMANCE OF FEED NOZZLES AS A FUNCTION OF OIL MIST PRESSURE GRADIENT

Feed nozzle						Nominal output in dm^3/min							Vent opening diam, mm
Type of nozzle	Designation	Openings				Pressure gradient in mm H_2O							
		Quantity	Diameter mm	Length mm	Area mm	50	125	200	300	500	750	1000	
Oil mist nozzle	DM-2	1	0.8	11	0,500	0.55	0.925	1.31	1,68	2,21	2,65	3.07	1,2
	DM-4	1	1,1	11	0,949	1.00	1.870	2.68	3,41	4,50	5,46	6.27	1,6
	DM-6	1	1,4	11	1,530	1.35	2,800	4,00	5,11	6.72	8,32	9.35	2,0
Dripping nozzle	DK-05	1	R = 0.35	10	0,192	-	-	-	0,36	0,50	0,67	0,81	0,8
	DK-1	1	R = 0.5	10	0,391	-	-	-	0,86	1,17	1,54	1.82	1,1
	DK-2	2	R = C.5	10	0,782	-	-	-	1,73	2,32	3,05	3.66	1,4
	DK-3	3	R = 0.5	10	1,173	-	-	-	2,54	3,50	4,59	5.46	2,0
	DK-4	5	R = 0.5	10	1,955	-	-	-	4,17	5.76	7,58	8,91	2,3
	DK-5	6	R = 0.5	10	2,346	-	-	-	4.98	6,88	8,73	10,30	2,4
Dripping spray nozzle	DKN-6	6	R = 0.5	10	2,346	-	-	-	3,69	5.18	6.60	7,75	2,4
		1	1,7	25	2,268								
Simple spray nozzle	DNz-1	1	0.6	35	0,281	-	-	0,50	0,61	0,81	0,98	1,12	0.8
	DNz-2	1	0,9	35	0,636	-	-	0.84	1,06	1,45	1,84	2.18	1,2
	DNz-3	1	1,1	35	0,949	-	-	1.12	1,68	2,18	2.66	3.13	1,5
	DNz-5	1	1,4	35	1,530	-	-	2,52	3,30	4,50	5,54	6,44	2,0
	DNz-8	1	1,7	35	2.268	-	-	5,04	6,44	8,40	10,36	11,76	2,4
High performance spray nozzle	DNw-1	1	1,7	35	2,268	-	-	3.92	5.60	7,84	9,80	11,20	2,4
	DNw-2	2	1,7	35	4,536	-	-	7,84	10,64	15,56	18,76	22,12	3.2
	DNw-3	3	1,7	35	6,804	-	-	11.76	15,40	21,28	27.54	31,92	4,0
	DNw-4	4	1,7	35	9,072	-	-	15,40	20,16	27,72	35.54	41,44	4,8
	DNw-5	5	1,7	35	11,340	-	-	19.04	24,64	34,16	43,40	50,40	5.2
	DNw-6	6	1.7	35	13,608	-	-	22,68	29,40	40,04	50,96	58,80	6,0
	DNw-7	7	1.7	35	15,976	-	-	26.32	33,88	45,92	57.68	67,20	6,4
	DNw-8	8	1,7	35	18,144	-	-	29.96	38,08	51,52	64,12	75,04	6,8
	DNw-9	9	1,7	35	20.412	-	-	33,88	42,56	56,56	70,28	82,04	7,2
	DNw-10	10	1,7	35	22,680	-	-	37.80	46,76	61.32	75,44	88,76	7,6
	DNw-11	11	1,7	35	24.984	-	-	41,16	51,52	65,80	81.76	95,20	8,0
	DNw-12	12	1,7	35	27.252	-	-	44.80	55,72	70,56	86.40	100,80	8,4
	DNw-13	13	1.7	35	29.520	-	-	47.88	58,80	74,48	90.00	106,40	8.8
	DNw-14	14	1,7	35	31.788	-	-	50.96	61.08	77,84	94,36	110,42	8,8

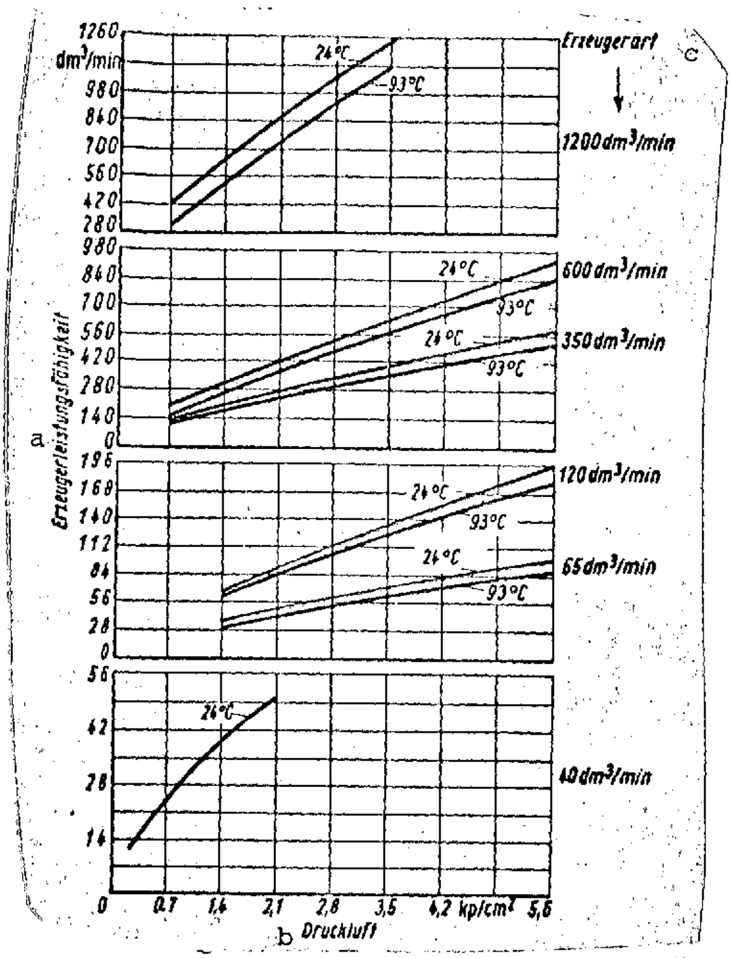

Fig. 23. Performance of standardized oil mist generators.

Key: a. Generator output; b. Compressed air; c. Type of generator; kp = kilogram force

9.2.2. Oil and Air Preheating

The quantity of oil divided into microscopic oil particles is primarily a function of oil viscosity and temperature. When oils with a viscosity of 300 to 500 cSt are atomized at a temperature of 38°C, we obtain an oil/air ratio of 4 mm3 oil in 1 dm^3 air. The approximate oil and compressed air preheating required to allow an oil/ /air ratio of 4 mm^3/dm3 in an oil mist generator and satisfactory operation of the feed nozzles can be seen in Fig. 24 as a function of oil viscosity and ambient temperature.

A number of remarks should be made concerning the graph:

the graph:

1. If operating conditions for the generator are below line I, no oil and compressed air preheating is necessary.

2. Between lines I and II, it is necessary to preheat the oil to the temperature delimited by line I. In practice, the oil is preheated to a temperature of 32 to 38°C. Generators which operate at ambient temperatures below 5°C must always be equipped with oil preheaters.

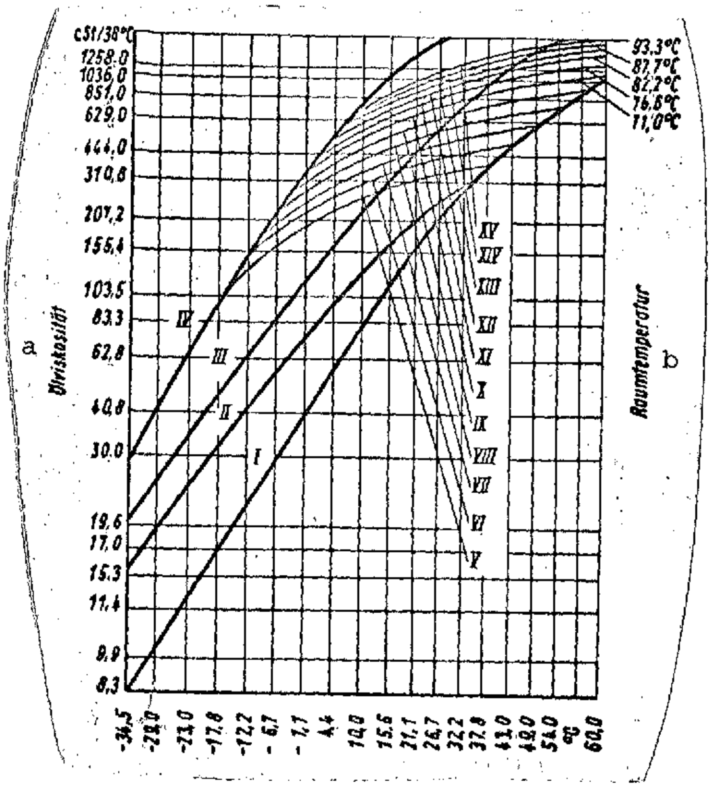

Fig. 24. Operating graph for air and oil preheating.

Key: a. Oil viscosity; b. Ambient temperature

3. Generators whose operating conditions lie above line II require oil and compressed air pre-heating. The oil must be preheated to the temperature determined by line I; the temperature for compressed air preheating is determined by line II. If the intersection of oil viscosity and ambient temperature should lie above line V (but below line IV), the compressed air preheating temperature can likewise be read off on line II; this point must be found on line II along curves V to XV.

4. Line III determines the minimum ambient temperature for condensation feed nozzles.

5. Line IV determines the minimum temperature for spray feed nozzles with an opening diameter of 1.7 mm.

6. The minimum ambient temperatures for spray and mist nozzles with opening diameters of less than 1.7 mm are located between lines III and IV and are a function of diameter.

9.2.3. Oil Refill Times for Generators

Oil refill times are calculated for generators which operate with a nominal oil/air ratio (4 mm3 oil in 1 dm^3 air) with the following formulae: /106

a) Generators with air preheating;

$$C = V/Q \cdot 4000\ h$$

b) Generators without air preheating:

$$C = V/Q \cdot 2000h$$

where C = operating time of generator between fillings in h
V = generator tank capacity in dm^3
Q = generator output in dm^3/min.

Longer refill times than 200 hours are not recommended. The capacity of oil tanks for mist generators is calculated with the following formula:

$$V = 0.25 \cdot C \cdot Q/1000\ dm^3$$

where V = tank capacity in dm^3
C = generator operating time between fillings in h
Q = generator output in dm^3/min.

9.3. Selection of the Type of Oil and Viscosity

The following types of oil are used in oil mist lubricating systems:

1. If EP oils are not expressly demanded, the following are used:

a) turbine oils for all industrial units,

b) motor oils for self-propelled units.

2. If EP oils are required, gearbox oils are used which are suitable for industrial and automotive gearboxes and can be atomized well.

Special oils are also being put on the market for oil mist lubrication, however. Oil viscosity is determined on the basis of the following principles:

1. At normal ambient temperature, oils with a viscosity of 107 to 148 cSt/38°C are used for most gears.

2. At lower ambient temperatures, oils of 41 to 107 cSt/38°C are used.

3. At very low ambient temperatures, oils of 7.3 to 63.6 cSt/ /38°C are used for ball bearings with high tangential velocities.

4. Oils with a viscosity of 148 to 213 cSt/38°C are used to lubricate elements under very heavy loads.

5. Oils with a viscosity of 317 to 481 cSt/38°C are used for machinery elements with large dimensions and severe operating conditions.

6. Oils with a viscosity of 577 to 2258 cSt/38°C are used for large, slow-moving, semienclosed gears.

The following must also be observed:

1. Oils with suspended solids, e.g. graphite, cannot be used without approval of the manufacturer, since they must satisfy special storage conditions.

2. Silicone oils can only be added in a ratio of 1:200,000.

3. Oils with active EP additives should only be used with great caution, since chemical reactions can occur in contact with an oil preheater.

4. Detergents, which have the ability of removing deposits that can form in bearings operating at relatively high temperatures, may not be added to EP oils. The same applies to additives meant to increase oil viscosity and thereby reduce excess mist formation. A number of such additives can also cause appreciable condensation of the oil microparticles in lines and thus produce an excessive drop in the mist's oil content.

9.4. Determining the Dimensions of Compressed Air and Oil Mist Lines

9.4.1. Compressed Air Lines

The following materials are recommended for compressed air lines:

-- galvanized steel tubing

-- copper tubing

-- anodized aluminum tubing

-- rubber or plastic hose.

Table 2 shows the pressure drop during the passage of compressed air at 7 kg/cm^2 through a 30 m long section of line as a function of inside diameter and air flow rate. Since the compressed air usually contains impurities (rust, scale, etc.) and water vapor, it is necessary to install screen filters with meshes of 25 to 40 μm and water separators downstream from them.

TABLE 2. PRESSURE DROPS IN COMPRESSED AIR LINES

Flow rate in dm^3/min at 7 kg/cm^3	Pressure drop over a 30 m section, in kg/cm^2. Inside diameter of line, in mm				
	7	9	12	16	21
56	0.14	-	-	-	-
112	0.35	0.07	-	-	-
196	1.12	0.21	0.07	-	-
420	-	0.91	0.21	0.07	-
560	-	1.61	0.35	0.14	-
980	-	-	0.98	0.28	0.07
1260	-	-	1.61	0.49	0.14
2800	-	-	-	2.31	0.56

The generator feed line should have a larger diameter than the connecting opening in the generator.

Compressed air pressure should be correspondingly higher in order to cover the pressure losses which occur in the installed units (filters, water separators, shutoff and reduction valves, etc.). /107

9.4.2. Oil Mist Lines

The same materials as used for compressed air lines can be used for the oil mist lines, but ungalvanized steel tubing can also be used. The latter must be coated with rust-inhibiting paint and covered with oil prior to the introduction of oil mist, however. In view of the relatively low oil mist pressure, it is not necessary to use such materials as hemp, varnish, etc. for sealing, particularly since these can block the openings of the feed nozzles.

The line should be designed in such a manner that as little oil particle condensation as possible occurs and free movement of the condensed oil to the generator tank is ensured.

A maximum oil mist velocity of 5 m/s in the lines is recommended. At higher flow velocities, excessive condensation of the oil microparticles occurs and it is not easy to keep oil mist pressure constant. The oil mist fed to condensation or spray nozzles can have higher flow rates than 5 m/s, but only in the lines which connect the nozzles with the main line and have inside diameters of less than 4.5 mm. The purpose of using higher oil mist flow velocities is to remove condensed oil microparticles from the lines and transport them to the lubrication points.

The lines should be dimensioned so that pressure drops from the generator to each feed nozzle are equivalent. The maximum line lengths to be recommended are shown in Table 3 for a number of inside diameters and flow rates for which the pressure drops do not exceed 20% of oil mist pressure. Lines of longer length can only be used after their flow resistances are checked.

TABLE 3. RECOMMENDED OIL MIST LINE LENGTHS

Inside diameter mm	Cross section mm^2	Maximum flow rate dm^3/min	Maximum line length m
3	7.1	5.6+ 3.1++	P:580
4.5	15.9	14+ 7++	P:205
7	38.5	16	6
8	50.2	20.5	7.5
9	63.6	29	11
11	95	40.5	15
12.5	122.7	53.5	18
15.5	188.7	85	23
21	346	150	30.5
27	572	244	38
35	962	420	49
41	1320	575	61
53	2206	940	73
63	3117	1342	73
78	4778	2080	73

\+ For one nozzle
\++ For two nozzles
P Oil mist pressure in mm H_2O

Explanation of Table 3:

1. The table has been compiled for an oil mist pressure of more than 400 mm H_2O. For oil mist pressures of 150 to 400 mm H_2O and for pressures below 150 mm H_2O in simple systems, the line lengths or flow rates must be divided by two.

2. The table assumes a minimum number of elbows, branches and other fittings. The major portion of the line must consist of straight sections. A change in the mist's direction of flow in the line causes condensation of the oil microparticles and also pressure drops corresponding to those over very long, straight lines.

3. The lines in a lubricating system should have a maximum of three different diameters.

4. In systems with compressed air preheating, this table can only be applied if the differences in ambient temperature at different lubricating points are not very great. If great differences in ambient temperature exist, large differences occur in feed nozzle output. The table discussed here can be applied to systems with compressed air preheating if at least one of the following conditions is satisfied:

a) Compressed air temperature should not exceed ambient temperature by more than 40°.

b) The distance from the generator to each feed nozzle must be as uniform as possible.

c) All feed nozzles should be installed at a distance from the generator which is greater than that calculated from the following formula:

$$L = T \cdot d/450,$$

where L = line length in mm

T = compressed air temperature in °C

d = inside diameter of line in mm.

If the system does not satisfy conditions a), b), or c), all lines must be heated in order to maintain the same temperature in all feed nozzles.

5. It has been assumed that the difference in oil mist pressure in the lines does not exceed 20% of nominal pressure.

It is likewise important to determine line slope and inside diameter. Minimum inside diameter for the oil mist line can be calculated from the following formula:

$$d = 1.7\sqrt{Q}$$

where d = inside line diameter in mm

Q = mist flow rate in dm^3/min.

Table 4 gives the recommended slopes of oil mist lines to provide regular removal of condensed oil to the generator or other tanks.

TABLE 4. SLOPE OF OIL MIST LINE

Oil viscosity	Slope of line in % Minimum ambient temp. in °C				
	-18	0	10	25	38
20	5.3	3.7	3.0	2.4	2.1
36	8.8	5.4	4.1	3.0	2.5
62	10,5	6.1	4.6	3.7	2.9
104	12.2	7.2	5.5	4.4	3.5
163	18.0	8.5	6.5	5.1	4.0
303	-	11.0	8,8	6.1	4,9
518	-	15.0	10.4	7.1	5,4
1036	-	-	14.4	9.0	6,7

Explanation of Table 4:

1. A line slope of 1% means that the line rises 10 mm over a length of 1000 mm.

2. The table is applied if the direction of oil condensate flow is opposite to the flow of mist.

3. If the oil condensate flows off in the direction in which the oil mist flows, however, a line slope is not necessary; rather, it is then laid horizontally. Collecting tanks with drainage openings are set up for periodic oil condensate removal. The distance between drainage tanks should not be greater than 300 times line diameter. The condensed oil can also be fed to the lubrication points.

4. The table applies to lubrication systems in continuous operation. In systems whose operation is interrupted once or twice in 24 hours, half the indicated line slope is used.

The primary line should in any case be inclined toward the generator in order to allow the condensed oil microparticles to drain into the tank. Since the condensation of oil particles /108
usually occurs at the beginning of the line, i.e., downstream from the generator, the gradient of this section is particularly important.

The accumulation of relatively large quantities of condensed oil in so-called "pockets" in the oil line must be avoided. Although small "oil pockets" do not completely shut off the flow of oil mist, they cause pressure drops which reduce the flow of oil mist to the lubrication points. If resistance in the "oil pocket" is equal to or greater than oil mist pressure, flow is cut off completely.

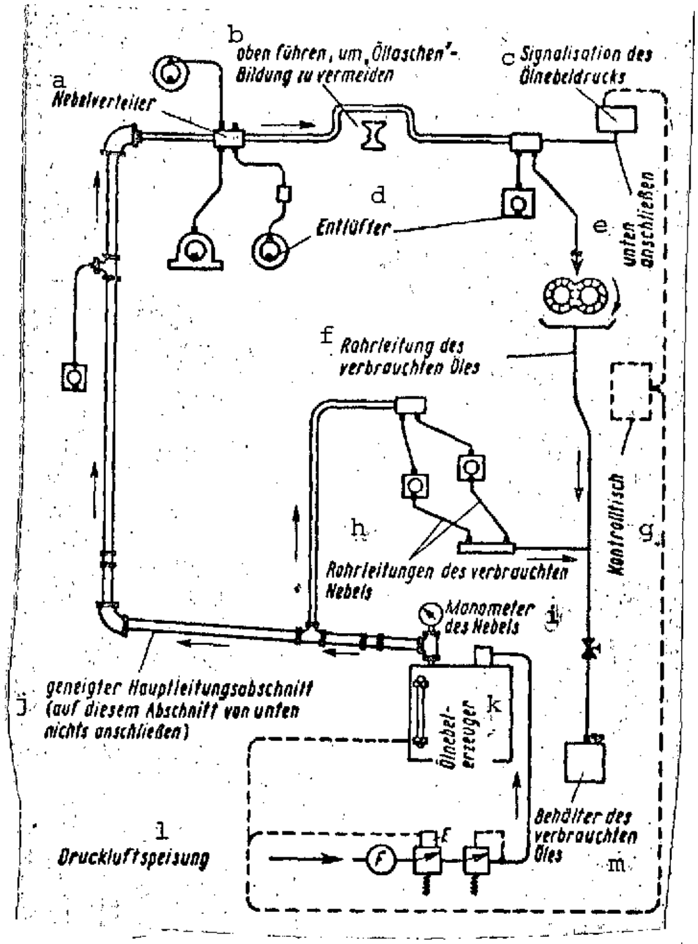

Fig. 25. Schematic of a line system.

Key: a. Mist distributor; b. Lay on top to avoid formation of "oil pockets"; c. Oil pressure transmitter; d. Vent; e. Connect at bottom; f. Line for used oil; g. Control desk; h. Lines for used mist; i. Mist pressure gauge; j. Sloped section of primary line (do not make connections to this section from below); k. Oil mist generator; l. Compressed air supply; m. Tank for used oil.

If the line which feeds the nozzles is inclined toward the primary line, it must connect to the primary line from above so no "oil pockets" can be formed. The "oil pockets" practically never form in sections of line connecting the feed nozzle to the primary line if inside diameter is less than 4.5 mm and oil mist pressure is more than 200 mm H_2O. In order to prevent "oil pocket" formation, oil mist drainage should occur at the lowest point in the line. If it is not feasible to avoid "oil pocket" formation but free discharge of the oil to the outside is possible, an opening with a diameter of 1.2 mm is made at the lowest point in the line, through which the condensed oil can drain.

If free drainage of the condensed oil to the outside is not possible, a tank with lines must be installed to collect the

The tank is connected to the lowest-lying points on the oil mist line. Tubing with the following inside diameters is used for this purpose:

3.7 mm in systems without compressed air preheating,

6.3 mm in systems with compressed air preheating.

To avoid the development of backpressure in the lines which drain off the condensate, a vent with a diameter of 1.2 mm is provided in the collecting tank. If this is not feasible, the diameter of the line for condensed oil drainage must be 9.5 mm or more.

A typical system of lines for oil mist and compressed air is shown in Fig. 25.

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